AD-775 818

DEVELOPMENT OF MANUFACTURING METHODS FOR BALLISTICALLY TOLERANT FIBERGLASS TUBULAR BELLCRANKS

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Fort Eustis, Virginia

January 1974

AD-775 818

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Eustis Directorate U.S. Army Air Mobility Research and Development Laboratory Fort Eustis, Virginia	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
DEVEOPMENT OF MANUFACTURING METHODS FOR BALLISTICALLY TOLERANT FIBERGLASS TUBULAR BELLCRANKS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Memorandum

5. AUTHOR(S) (First name, middle initial, last name)
I. E. Figge, Sr.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1974	~~31~~ 34	2

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. House Task 71-12 d.	9a. ORIGINATOR'S REPORT NUMBER(S) USAAMRDL Technical Memorandum 3 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory Fort Eustis, Virginia

13. ABSTRACT

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Unclassified
Security Classification

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ballistically tolerant						
Fiberglass tubular bellcranks						

Unclassified

Security Classification

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DEVELOPMENT OF MANUFACTURING METHODS FOR BALLISTICALLY TOLERANT FIBERGLASS TUBULAR BELLCRANKS

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SUMMARY

The purpose of this investigation was to develop manufacturing methods for the ballistically tolerant tubular/sandwich CH-47 forward bellcrank with the goals of optimizing production costs and weight, while achieving structural repeatability. Complete fabrication details are presented. Ballistic, fatigue, and static tests, conducted at -65°F, 75°F, and 180°F, showed that the bellcrank met the design requirements. The manufacturing techniques developed resulted in both substantial weight savings (1.65 pounds compared to 3.4 pounds for a metal bellcrank) and cost savings ($68.60 compared to $135.00). A "slotting" technique that localized the ballistic damage on the exit face sheet and prevented gross delaminations was developed.

FOREWORD

The author acknowledges Messers. B. L. Karp, E. H. McIlwean, and particularly M. C. Dail (deceased), all of the Structures Area, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, for their significant contributions to this program. Without their ingenuity and resourcefulness, this program would not have been possible.

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INTRODUCTION

Reference 1 reports the development of a CH-47 forward bellcrank using fiberglass tubular/sandwich construction, which demonstrated improved ballistic tolerance, reduced weight, and potentially lower production costs as compared to metal bellcranks.

The primary purpose of this investigation was to develop manufacturing methods for the tubular/sandwich bellcrank concept with the goals of optimizing production costs and weight, while achieving structural repeatability.

Criteria for structural and ballistic impacts, which were developed in the previous investigation,[1] remained the same. In order to demonstrate that the structural objectives were met, static, dynamic, and ballistic tests were conducted at −65°F, 75°F, and 180°F.

DEVELOPMENT OF FABRICATION PROCEDURES

BELLCRANK

The basic tubular concept developed in Reference 1 was selected for further study since it permitted straightforward use of existing low-cost fabrication techniques. A schematic of the tubular bellcrank is shown in Figure 1, and a detailed drawing of the bellcrank is presented in Appendix I. Prepreg cloth, 181-style, was used in the construction of all components of the bellcrank except the bearings and bearing sleeves. Complete material properties and cure cycles are presented in Appendix II. The bellcrank consisted of three major elements: face sheets, tubular members, and end attachments. In all cases, matched metal molds were used to fabricate the major elements. The elements were then assembled and bonded using FM-1000 adhesive (see Appendix III). The fabrication of each element is discussed in detail in the following sections.

FACE SHEETS

Although research indicated that the concept developed in Reference 1 provided significant increases in ballistic tolerance, one deficiency was observed during ballistic testing in that investigation. It was found that when the projectile impacted the tubular portion of the bellcrank, it invariably caused gross delamination of the exit face sheet (see Figure 2). Numerous adhesive systems and overwrapping techniques were used in Reference 1 to no avail. No distinguishable differences in the extent of delamination were observed between ductile or brittle adhesive systems.

In the current program, it was found that preferential slotting of the exit face (see Figures 3 and 4) confined the delamination to the impact area. The slotting did not significantly reduce the undamaged structural strength, since the face sheets were designed as secondary load paths in the event of tube failure. The forward bellcrank is located close to the transmission housing and, as such, can be impacted only from one side. Since the delamination occurs only on the exit face, it was necessary to slot only that face for this application.

The spacing of the slots was selected as a function of the length of a fully tumbled round. In this case, the maximum threat was assumed to be a fully tumbled .30 caliber AP projectile that was 1.44 inches long. The slot spacing was slightly larger than one-half the length of the projectile (.75 inch). In this manner, the maximum length that could be lost (delaminated) was 2.25 inches or approximately 1.6 times the tumbled length. The length of the slot (approximately 1-1/8 inches) was slightly larger than the width of the tubular element.

The face sheets were fabricated in pairs using matched metal molds as shown in Figure 5. Three plies of prepreg 181 cloth were pattern cut to size and placed in the molds to form the stepped doublers for the attachment and pivot bearing areas. Four additional

plies of 181 cloth were pattern cut and placed in the molds to complete the face sheet.

J. P. Stevens style-6 fiberglass peel ply was used on all surfaces that would later be bonded. The matched metal molds were placed in a press and the face sheets cured in accordance with Appendix II. The slots were cut in the exit face with a 100-grit diamond bandsaw after curing. This completed the fabrication of the face sheets, which were then ready for final assembly.

TUBULAR ELEMENTS

The tubular elements were wound with six plies of 181 cloth on a square mandrel, as shown in Figure 6. Again, peel ply was used. The uncured tube/mandrel was placed in the matched metal molds and placed in the press for curing (see Figure 7). After curing, the mandrels were removed and the angles on each tube were cut to final dimensions to allow assembly into a triangular platform, using the jigging shown in Figure 8. The slots to accept the end attachment were then cut, completing the operation.

END ATTACHMENTS

The end attachments shown in Figure 9 were fabricated in pairs in the matched metal mold shown in Figures 10 and 11. Eight-ply triangular-shaped doublers were integrally fabricated as part of the end attachments. These doublers served to align the tubular element during final assembly and to provide additional stiffening and bond area for the face sheet. The end attachments were four plies thick on the output attachment and twelve plies thick on the input attachment.

BEARINGS

Standard sleeve bearings as used in the existing metal bellcrank were used. The pivot bearing was designed to offset the bellcrank in order to permit fit and function in the CH-47 helicopter. Details of pivot bearing assembly are shown in Figure 1 and Appendix I. The internesting metallic sleeves holding the three pivot bearings were die formed (two step) from annealed 6061 aluminum. After forming, the sleeves were heat treated to the T6 condition. Ballistically tolerant bearings have been developed (see Reference 1). However, due to the fit and function requirement, they were not incorporated; rather, the existing metallic fitting was used.

FINAL ASSEMBLY

Final assembly was achieved by placing the elements in a precision positioning jig, as shown in Figures 12 and 13. FM-1000 adhesive was used in all bonded areas. The FM-1000 adhesive was cured in a hydraulic press at 350°F and with a nominal pressure on the bonded areas of 50 psi. After curing, the completed assembly was precision jig trimmed to final dimensions in a tensile cutter (high-speed router). Holes for the pivot and sleeve bearings were then jig drilled. The pivot bearing assembly was coated with Epon 828 resin/DTA catalyst and was inserted in the bellcrank, and the retainer sleeve

was press-fit into place. The sleeve bearings for the input and output attachments were slip-fit into place. No adhesive was used since the bearings are designed to slide to accommodate and position the self-aligning rod end bearings. The completed bellcrank is shown in Figure 14.

COST AND WEIGHT ESTIMATES

COST

The cost estimates are based on using high-volume production techniques, such as die-cutting the fiberglass cloth to shape, using jig positioning of material and cured elements, and using rapid-cure resin systems. Table I presents an estimate of the materials and man-hours required. Costs were estimated at $8.00/hour, which includes overhead, G&A, and profit.

TABLE I. COST ESTIMATES

Materials		Cost ($)
Prepreg 181-style fiberglass cloth, 2.5 sq yd		50.00
FM-1000 film adhesive, 120 sq in.		2.00
Aluminum alloy for pivot bearing sleeve		1.00
Bearings, 3 @ $1.20		3.60
		56.00
Fabrication	**Hours**	**Cost ($)**
Die cutting of fiberglass cloth (face sheets and end attachments)	.2	1.60
Placing fiberglass cloth in dies	.4	3.20
Curing (based on RF cure)	.05 Equip Time	-
Tube fabrication, including curing	.04	3.20
Cutting tubular elements to finished dimensions	.1	.80
Jig assembly of face sheets, tubular elements, and end attachments	.1	.80
Curing	1.0 Equip Time	-
Final trim	.1	.80
Fabrication of pivot bearing sleeve	.1	.80
Installation of bearing	.1	.80
	2.19	12.00
Total		68.60

The total estimated cost, $68.60, compares favorably with the metal bellcrank cost, approximately $135.00.

WEIGHT

The completed weight of the tubular/sandwich bellcrank was 1.65 pounds as compared to 3.4 pounds for the existing magnesium bellcrank, which amounts to a weight reduction of 52 percent. Nominal additional weight savings could be achieved if the pivot attachment fitting was modified to eliminate the need for the pivot bearing offset.

GENERAL REMARKS

The fabrication procedures used for the fiberglass bellcrank show that both cost and weight savings are achievable using the tubular/sandwich construction. The remainder of this memorandum covers the testing that was conducted to demonstrate the structural adequacy of the bellcrank.

TEST EQUIPMENT AND PROCEDURES

GENERAL

The existing CH-47 forward bellcrank is subjected to flight loads typically less than 100 pounds. The highest measured values have not exceeded 135 pounds. The maximum possible load that can be applied to the bellcrank is 562 pounds. However, the controlling factor is the parked load condition when the hydraulic boost has bled down. Under the worst conditions, the component can be subjected to a compressive load of approximately 2000 pounds.

In a contractual research program conducted by Boeing-Vertol, the proof loads have been set at 1860 pounds for static compression and ±350 pounds for dynamic loading. Since strength is reduced about 40 to 50 percent at elevated temperature, the bellcrank studied in this program was designed for a load of -4000 pounds at room temperature and ±350 pounds for dynamic loading. The design load of -4000 pounds at room temperature was selected to obtain a reasonable degree of assurance that the bellcrank could withstand a 2000-pound load at 180°F (operational requirement).

An elevated temperature of approximately 180°F was achieved by placing banks of heat lamps on both sides of the bellcrank being tested. Temperature probes indicated that the temperature was uniform to within ±5°F over the entire bellcrank. Each bellcrank was allowed to soak at temperature for approximately 2 hours prior to testing.

A low temperature of approximately -65°F was achieved by surrounding the bellcrank with a sheet-metal container filled with a slurry of crushed dry ice and alcohol. Thermocouples placed inside the bellcrank indicated that the temperatures were uniform to within ±10°F. Due to the difficulty of maintaining uniform temperatures for prolonged periods, testing was initiated as soon as the specimen reached the desired temperature.

Under combat conditions, the probability of a helicopter's receiving more than two ballistic hits in a single area is small. After a hit, an arbitrary requirement of 30 minutes of flight time was considered to be sufficient to get the damaged helicopter back to base, or at least into safe territory. Typically, 100 load cycles at ±100 pounds might be experienced during this period. In this program, the specimens were subjected to fully tumbled impacts at 1800 feet per second, which has been shown to be the most damaging velocity. Following the ballistic tests, a minimum of 10,000 load cycles at ±350 pounds were applied.

Environmental degradation of the bellcrank was not considered as an important design consideration, since the materials, i.e., fiberglass, epoxy, and film adhesives, used in construction have been subjected to environmental testing and have demonstrated

essentially no degradation. Seven fiberglass bellcranks were manufactured for testing; two metal bellcranks were tested as baselines. Static, fatigue, and ballistic tests were conducted on the bellcranks according to Table II.

TABLE II. TEST SCHEDULE

Bellcrank	Test Temp (°F)	Ballistic (1)	Fatigue (2)	Static (3)
1	75			X
2	75			X
3	180			X
4	-80*			X
5	75	X	X	X
6	180	X	X	X
7	-65	X	X	X
8 (metal)	75	X	X	X
9 (metal)	75	X		

Numbers in parentheses indicate test sequence.

*Test conducted at lower than desired temperature of -65°F.

BALLISTIC TESTS

The bellcranks were impacted with fully tumbled .30 caliber armor-piercing ammunition at an approximate velocity of 1800 feet per second. Tumbling of the projectiles was achieved with a smooth-bore rifle with the barrel end cut at an angle. Projectile velocities were measured with electronic witness plates spaced 4 feet apart and with a high-speed digital counter. Photographs of each ballistic test were taken with a 16mm Fastex camera operating at 18,000 frames per second.

STATIC AND FATIGUE TESTS

A 10,000-pound-capacity closed-loop hydraulic test machine was used to perform the static and fatigue tests. Loads were monitored with a Brush recorder, a recording oscilloscope, and an X-Y plotter. Cyclic frequency for all fatigue tests was 1 hertz. Static preloads for the ballistic tests were achieved by hanging weights on the ouput bearing of the bellcranks.

TEST RESULTS

FIBERGLASS TUBULAR BELLCRANK

In general, the fiberglass tubular bellcranks behaved as anticipated, based on the results in Reference 1. Test results are presented in Table III. The "slotting" technique limited the damage to only those "tabs" (material between slots) that were impacted. Temperatures of approximately -65°F resulted in the highest failing loads. The results for both the undamaged and the ballistically damaged bellcrank at -65°F were identical. The lowest failure loads were recorded at +180°F. In the undamaged specimen at +180°F, an FM-1000 adhesive failure was observed between the skin and the tubular elements. This was the only test in which the primary mode of failure was an adhesive failure. Typically, a shear failure of the skin and tube in the pivot area was observed (see Figure 15).

In the ballistically impacted specimens, an attempt was made to sever the tubular element between the pivot bearing and the output bearings. Although the bellcranks were capable of withstanding cyclic and static loads far in excess of flight load in the damaged condition without failure or signs of crack propagation, the deflections measured at the input bearing were more than desired (see Table III). In the case of bellcrank 7, in which the tubular element was not totally severed, the measured deflections were approximately 4.7 times smaller than those in bellcranks in which total severing of the tube occurred. Use of a rectangular tubular element, in which the frontal dimension is greater than the dimension of the fully tumbled threat, would prevent total severing of the element on ballistic impact and would thus reduce the deflections to a more acceptable range.

METAL BELLCRANK

A study conducted under contract, Reference 2, indicated that the existing metal forward bellcrank of the CH-47 was one of the four most vulnerable components in that flight control system. Limited tests conducted on the two standard metal bellcranks tested to provide baseline data for this program indicate that the metal bellcranks can survive a .30 caliber threat (see Table III, bellcranks 8 and 9). Impacts at approximately 1700 feet per second on the thinnest legs of the bellcranks were insufficient to cause complete failure. Muzzle velocity (~2750 feet per second) impacts were sufficient to cause through failure of the thinner legs, but only 80 percent failure of the thickest leg. Even with two nonthrough impacts and one through impact, the bellcrank was capable of operating at ±350 pounds (approximately three times flight load) without appreciable deflections or indications of crack propagation. A second bellcrank (No. 8) failed at 8000 pounds after an 80 percent loss of the thickest leg. Impacts in the bearing areas, which represent a relatively small percentage of the total frontal area of the bellcrank, could, where the frontal area is less than the dimension of the tumbled threat, result in complete severing of that area. Impacts in the

metallic bearings themselves normally result in bearing seizure.

Although the metal bellcranks demonstrated that they could continue to function after a .30 caliber impact, it was consistently observed that, upon impact, an extensive flash occurred. In an unpublished study, similar impacts on other magnesium components produced flashes that were more than adequate to ignite a fuel/vapor mixture. Obviously, the condition represents a serious safety threat. The fiberglass bellcranks, on the other hand, being designed to allow the projectile to pass with a minimum of resistance, did not cause any flash.

TABLE III. TEST RESULTS

Bellcrank	Test Temp (°F)	Ballistic Conditions: Type	Ballistic Conditions: Load (lb)	Ballistic Conditions: % Tumb	Ballistic Conditions: Vel (fps)	Fatigue: Hertz	Fatigue: Load (lb)	Fatigue: Cycles	Max. Defl (in.)	Failure Load (Input) (lb)	Remarks
1 (without slotted exit face)	75					.1	−2070(1) +700	1 1		−4300(2)	Slight local failure (bearing type) at input attachment due to fatigue loading. At 4100 pounds, loud pop occurred; load dropped to 3200 pounds, increased to failure; failed at pivot bearing attachment.
2	75									−4700	Failed at pivot bearing attachment.
3	180									−2550	Adhesive failure between face sheet and tube in short leg.
4	−80									−4900	Failed at pivot bearing; partial debond between face sheet and tube in short leg.
5	75	.30 AP(1)	−350	Full	1804	1	±200(2)	5000	±.025		Test terminated at end of step (6).
						1	±400(3)	5000	±.14		
						.1	−1250(4)	1	.15		
						.1	+600(5)	1	.38		
						1	±900(6)	830	±.53		
6	180	.30 AP(1)	−350	Full	1820	1	±350	10,000	±.14	−1300(2)	Spec. overloaded at start of fatigue test, causing rips in each face sheet approx. 3 in. long. No crack propagation due to cycling; buckling failure of skins.
7	−65	.30 AP(1)	−350	Full	1756	1	±350(3)	10,000		−4900(4)	Two impacts did not sever tubular element. Failed in impact area.
		.30 AP(2)	−350	Full	1700				±.03		
8 (metal)	75	.30 AP(1)	−350	Full	2768	1	±350(2)	10,000		Approx. 8000(3)	Impacted thickest section approx. 80% penetration. Failed at impact area.
9 (metal)	75	.30 AP(1)	−350	75	1716						Shots 1 and 2 did not totally sever thin legs. Shot 3 caused through failure.
		.30 AP(2)	−350	75	1707						
		.30 AP(3)	−350	Full	2809						

Numbers in parentheses denote test sequence.

Sign convention: − indicates push on input bearing, + indicates pull on input bearing.

CONCLUSIONS

It is concluded that:

1. Ballistically tolerant bellcranks, capable of satisfactory operation at −65° to 180°F after sustaining a fully tumbled .30 caliber impact, can be fabricated using fiberglass tubular element/sandwich construction at substantially less cost and weight than a metal bellcrank.

2. "Slotting" localizes ballistic damage to the impact area and eliminates gross delamination of the exit face sheet of a bellcrank.

3. Rectangular tubular elements having a frontal dimension greater than the length of a fully tumbled projectile must be used in future components to prevent total severing of the tubular elements, thus reducing the bellcrank deflections due to operational loads.

4. Based on limited data, the existing metal bellcrank can survive a .30 caliber impact, with the exception of the bearing attachment areas; however, flashing consistently occurs upon impact sufficient to cause ignition of a fuel/vapor mixture, thus increasing the threat of in-flight fires. No flashing occurs in the fiberglass bellcranks.

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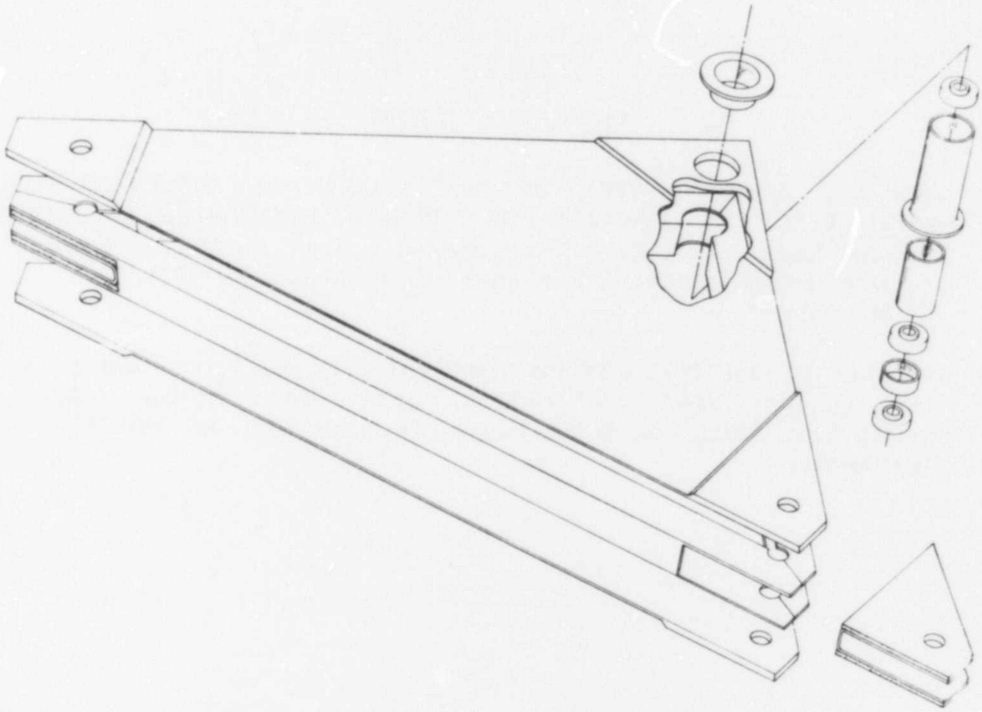


Figure 1. Exploded View of Square Tube Bellcrank.

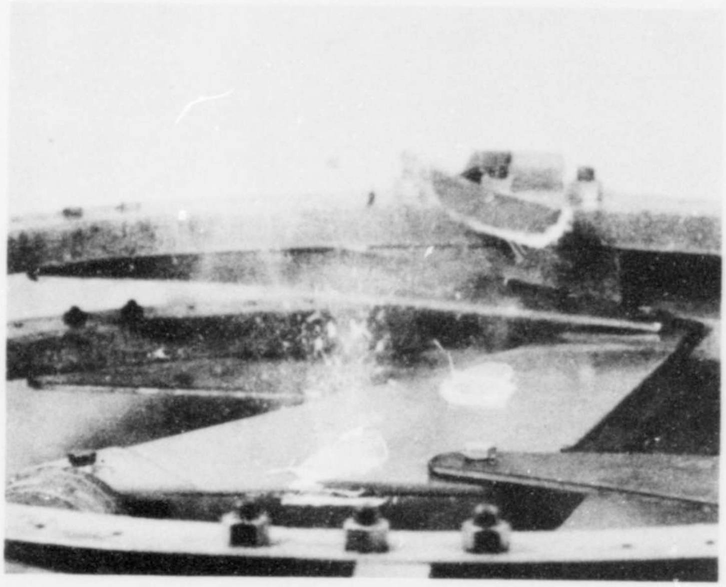


Figure 2. Delamination of Exit Face Sheet Caused by Tumbled .30 Caliber Impact.

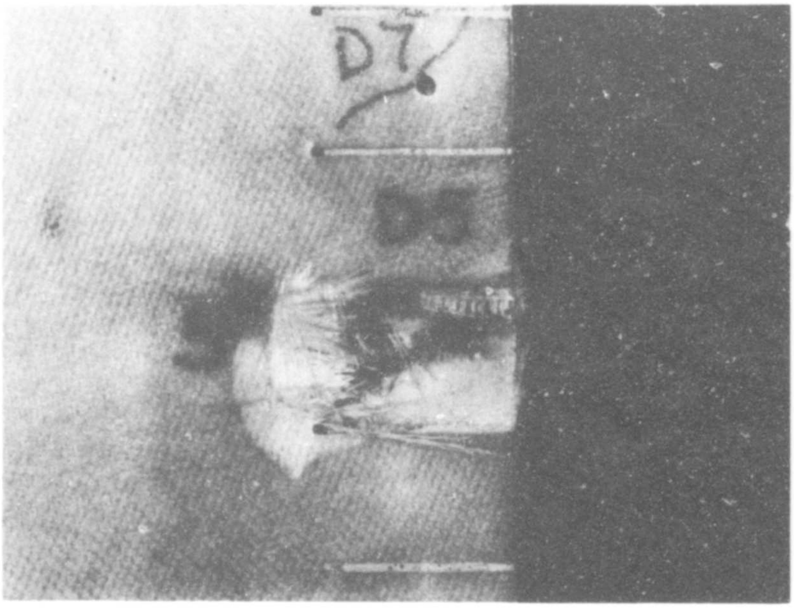


Figure 3. Localized Delamination of Exit Face Sheet Resulting From "Slotting".

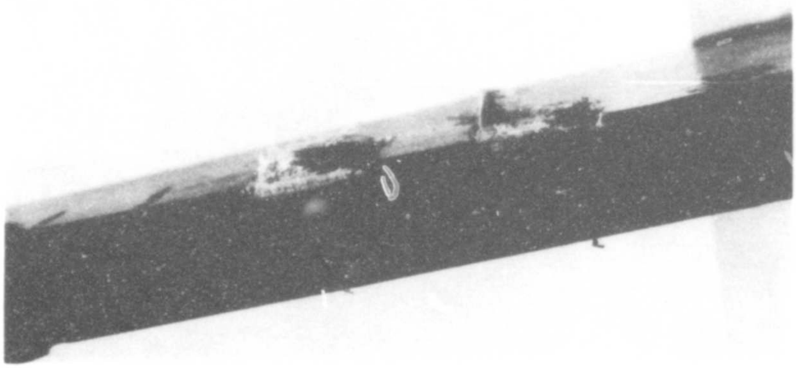


Figure 4. Edge View of Two .30 Caliber Impacts of Slotted Tubular Bellcrank (Note Minimal Delamination).

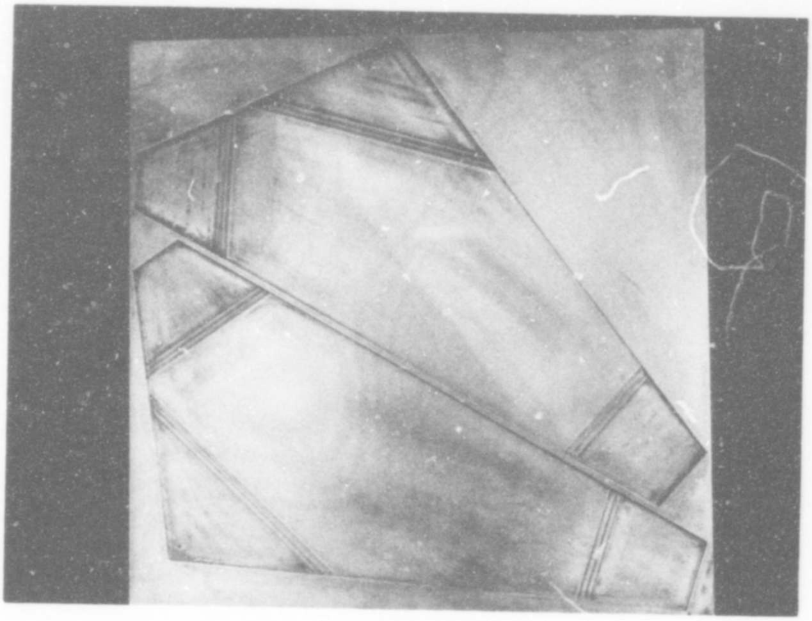


Figure 5. Aluminum Matched Metal Molds Used To Fabricate Face Sheets.

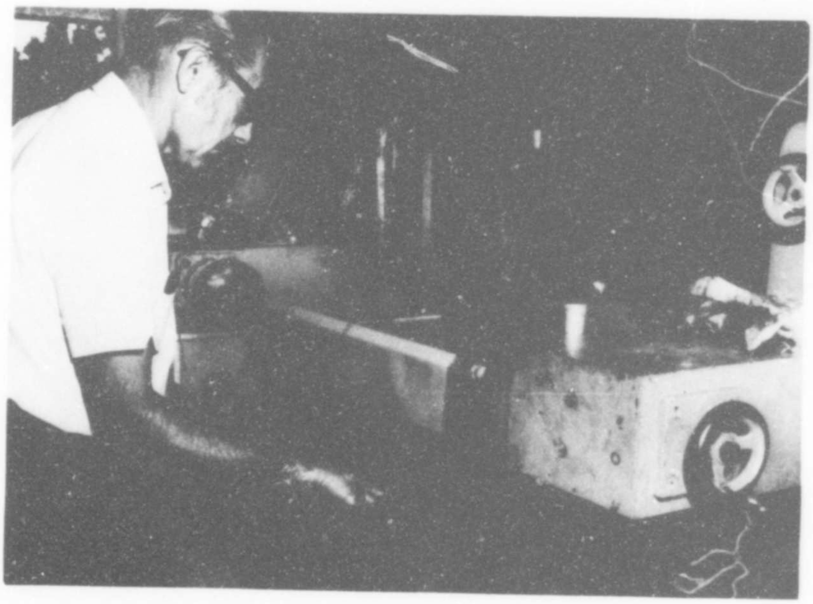


Figure 6. Winding of Glass Cloth Tubular Elements.

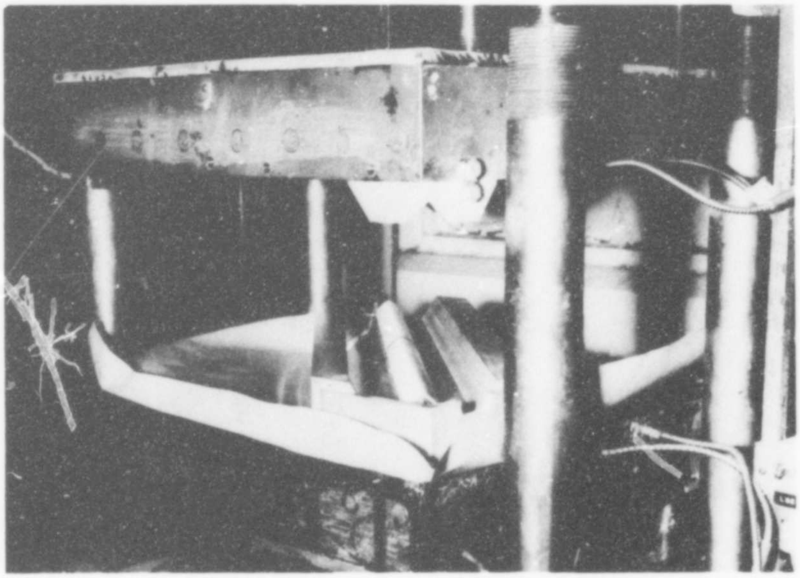


Figure 7. Aluminum Matched Metal Molds Used To Fabricate Tubular Elements.

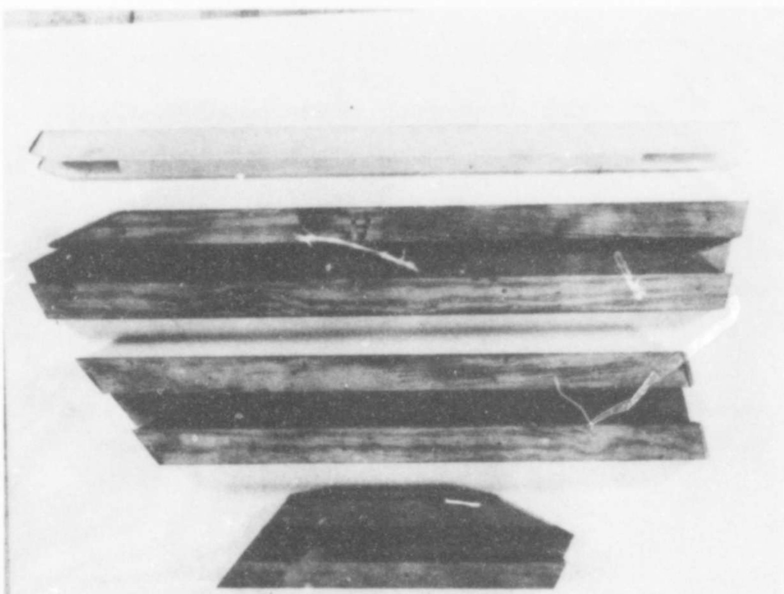


Figure 8. Jigging Used To Cut Tubular Elements to Final Dimensions.

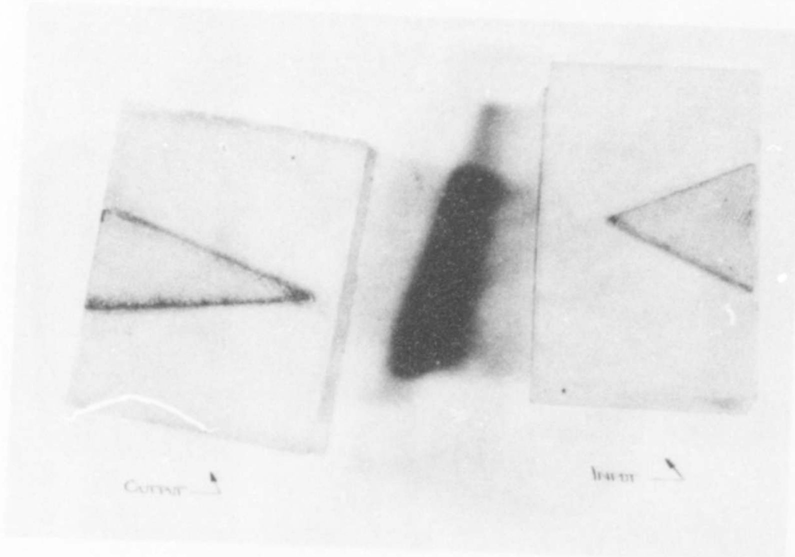


Figure 9. End Attachments.

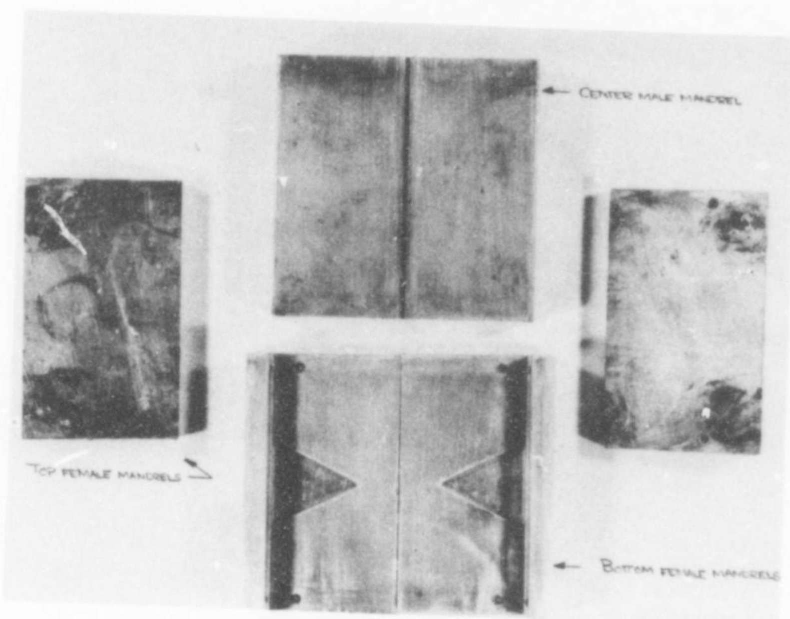


Figure 10. Aluminum Matched Metal Molds Used To Fabricate End Attachments.

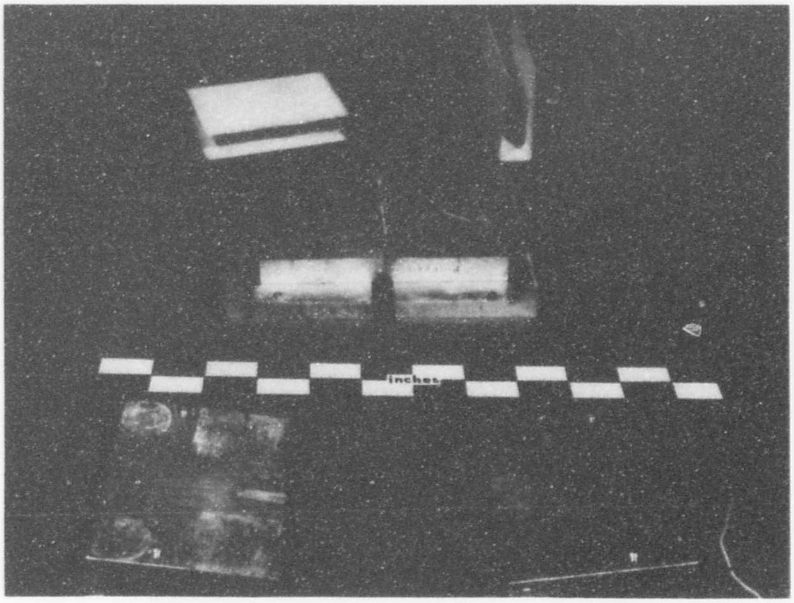


Figure 11. Exploded View of Aluminum Matched Metal Molds Used To Fabricate End Attachments.

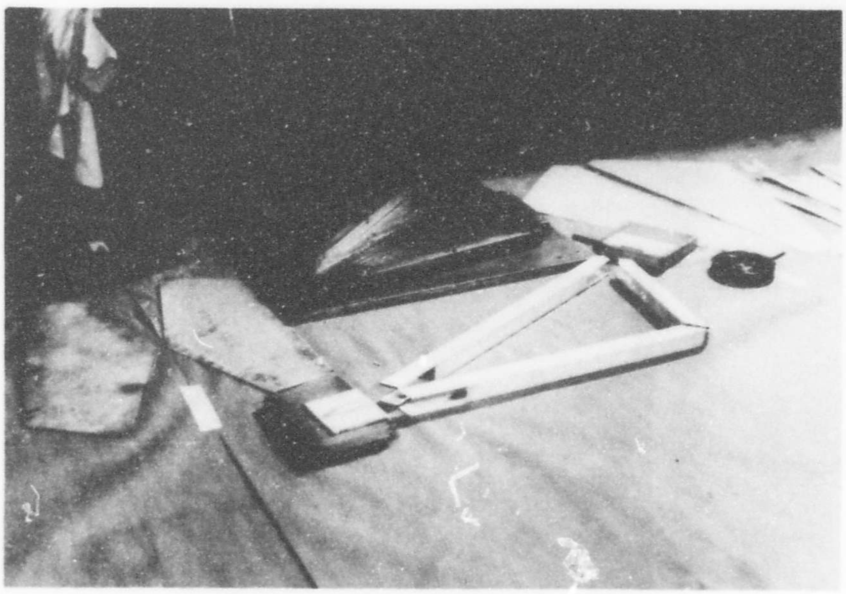


Figure 12. Final Assembly Jigging.

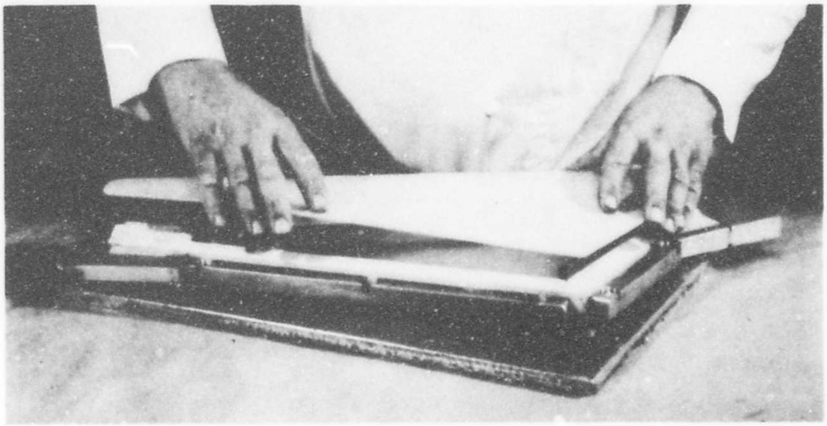


Figure 13. Bellcrank Being Assembled.

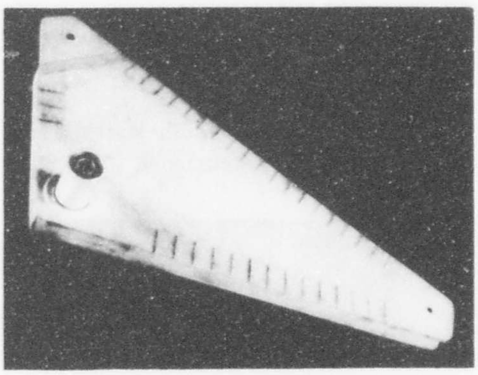


Figure 14. Completed Bellcrank.

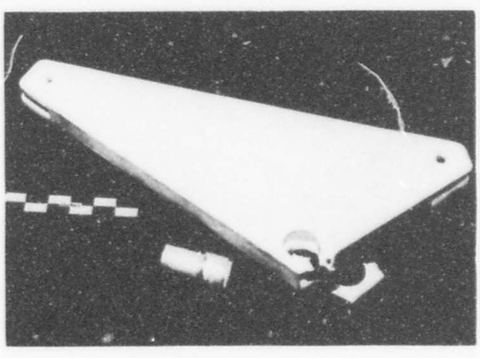
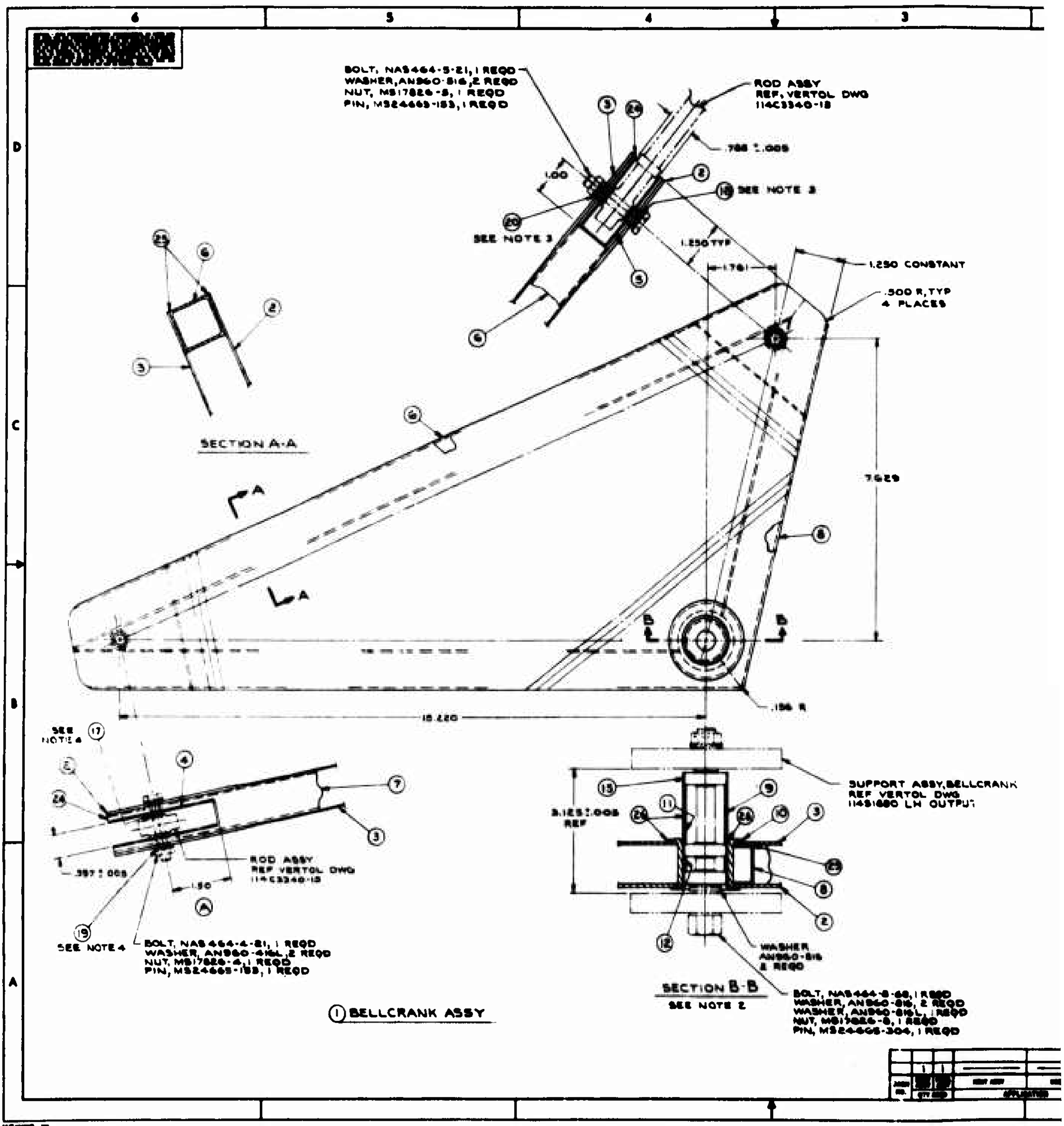
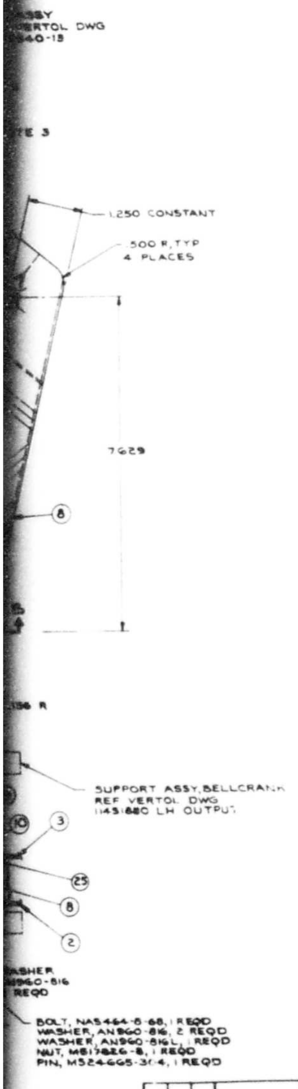


Figure 15. Typical Failure Mode.

APPENDIX I
DETAILED DRAWING OF TUBULAR BELLCRANK



ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	DIM 1.50 WAS .54.		



NOTES

1. REMOVE ALL SHARP EDGES AND BURRS.
2. 1.4975 $^{+.0010}_{-.0000}$ DIA HOLE TO BE MADE IN BELLCRANK TO ACCOMMODATE RETAINER, ITEM 10.
3. .4388 $^{+.0008}_{-.0000}$ DIA HOLE TO BE MADE IN BELLCRANK TO ACCOMMODATE BUSHINGS, ITEMS 18 AND 20.
4. .3763 $^{+.0002}_{-.0002}$ DIA HOLE TO BE MADE BELLCRANK TO ACCOMMODATE BUSHINGS, ITEMS 17 AND 19.
5. ITEMS 2 THRU 8 AND ITEM 24 TO BE SECURED WITH ITEM 25, FILM ADHESIVE.
6. ITEMS 9 THRU 12 TO BE SECURED WITH ITEM 26, EPOXY RESIN.

QTY REQD			FIND NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	CODE IDENT	MATL SPEC
		AR	26		EPOXY RESIN		
		AR	25	FM-1000	FILM ADHESIVE	07542	
		AR	24		FOAM FILLER		
			23		BULK MATERIAL		
			22				
			21				
		1	20	NAS77-5-25	BUSHINGS		
		1	19	77-4-28			
		1	18	75-5-010			
		1	17	NAS75-4-011	BUSHINGS		
			16				
		3	15	MS20201KP8A	BEARING		
			14				
			13				
		1	12	20071039-2	SPACER		
		1	11	039-1	SPACER		
		1	10	038-1	RETAINER		
		1	9	031-1	HOUSING		
		1	8	040-8	TUBE 1x1x.062		
		1	7	-7	TUBE 1x1x.062		
		1	6	-6	TUBE 1x1x.062		
		1	5	-5	U-FIXTURE		
		1	4	-4	U-FIXTURE		
		1	3	-3	SIDE PLATE, RH		
		1	2	-2	SIDE PLATE, LH		
			1	20071040-1	BELLCRANK ASSY		
		1					

PARTS LIST

DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON DECIMALS .X ± .1, .XX ± .03, .XXX ± .010; ANGLES ± 1/2°

MACHINED SURFACES 125 AND EXCEPT AS NOTED

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

BELLCRANK, MMT

BELLCRANK ASSEMBLY

SIZE	CODE IDENT NO.	DWG NO.	REV
F	81996	20071040	

SCALE 1/1 SHEET 1 OF 1

APPENDIX II
PROPERTIES AND CURE CYCLES FOR 181-STYLE PREPREG CLOTH

WBC 3201

DESCRIPTION

WBC 3201 is an epoxy-novolac resin reinforced with fiberglass fabric.

POLYMER: Epoxy-novolac.

REINFORCEMENTS: Normally supplied on 181/Volan A glass but is available on various other types of reinforcements.

AVAILABILITY: Tapes and broadgoods.

RECOMMENDED APPLICATIONS

WBC 3201 is a general-purpose epoxy-novolac based compound which produces excellent laminates for use at temperatures of up to 400°F. Laminates produced from WBC 3201 exhibit outstanding mechanical properties, including high interlaminar shear strength. This material is easily bonded to various substrates, including copper sheet, and has been used successfully in many electronic applications.

TYPICAL PHYSICAL PROPERTIES

Resin Solids Content	%	WBC Method R_3	36-44
Flow	%	WBC Method F_1	12-20
Volatiles Content	%	WBC Method V_3	3 Max
Tack (Minimum)		Seconds	30
Drape (Minimum)		Inches	8/32

TYPICAL PROPERTIES OF LAMINATES

	ASTM METHOD	
Flexural Strength (RT), psi	D-790-59T	90,000
Flexural Strength, psi (aged @ 300°F for ½ hr)	D-790-59T	60,000
Flexural Modulus (RT) X 10^6	D-790-59T	3.7
Flexural Modulus X 10^6 (aged @ 300°F for ½ hr)	D-790-59T	3.0
Tensile Strength (RT), psi	D-638-61T	58,000
Tensile Strength, psi (aged @ 300°F for ½ hr)	D-638-61T	45,000

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TYPICAL PROPERTIES OF LAMINATES – Continued

	ASTM METHOD	
Compressive Strength (RT)	D-695-54	55,000
Compressive Strength, psi (aged @ 300°F for ½ hr)	D-695-54	33,000
Dielectric Constant IMC	–	4.56
Arc Resistance, sec	–	100

CURE CONDITIONS

WBC 3201 can be successfully cured under a wide range of conditions; the following cure cycle is typical and is adequate for most applications:

	Initial Cure		Post Cure	
Pressure (psi)	Temp (°F)	Time (hr)	Temp (°F)	Time (hr)
5–50	325	3	350	1

APPENDIX III
PROPERTIES AND CURE CYCLES FOR FM-1000 STRUCTURAL ADHESIVE FILM

PROPERTIES

FM-1000, an unsupported film, is designed for structural bonding of both sandwich and all-metal constructions.

Physical strengths (shear strength over 12,000 psi on steels and peel strengths up to 300 inch-pounds on metal sandwich) are obtainable under a wide variety of processing conditions. Proper design of aluminum structures allows the metal to be stressed to or near ultimate strength levels. Low-temperature peel strength is particularly noteworthy.

FM-1000 adhesive film has been completely evaluated against the requirements of MIL-A-5090D and found to surpass all requirements by an extremely wide margin.

FM-1000 adhesive film may be used for bonding of all metals (including copper), wood, most plastics, and all available sandwich combinations.

Primer is not required for either face or core. However, two primers are available for use where processing requires "tacking" of film in place or protection of cleaned details. A slight increase in all properties results. BR-1009-8 is used for "tack" assembly at room temperature, while BR-1009-49 is used for "heat tacking" at 175°F.

CURING PROCEDURE

1. Primer is unnecessary. Where desired, a single roller or sprayed cross coat is adequate.

2. FM-1000 adhesive film is placed between surfaces to be bonded. Colored separator may be removed at any time before closing the assembly.

3. In general, FM-1000 should be cured for 60 minutes at 315° to 350°F, under 5 to 50 psi pressure. A typical bonding cycle might use a 1-hour heat-up to 340° ± 10°F and a cure of 1 hour at top temperature. Bonding conditions may vary considerably, with heat-up rates ranging from 0 to 180 minutes and curing temperatures ranging from 315° to 400°F. Curing time, of course, is a function of cure temperature. In this program, a cure cycle of 60 minutes at 350°F and 50 psi was used in conjunction with BR-1009-8 tack primer.